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Service Lifetime and Disposal Pathways of Business Devices

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Abstract

Product lifetimes and disposal pathways are essential aspects of dynamic material flow analyses (MFAs), which have often been used to model stocks and flows of electronic devices and the resources they contain. Existing studies mainly focus on the use and disposal of electronic devices by private consumers. The specific handling of business devices has rarely been assessed. This article presents the results of a study conducted in Switzerland in 2015, comprising interviews with 28 companies. Devices included are desktop and laptop computers, mobile phones, monitors, televisions, external hard disk drives and servers. Results are compared to data collected from Swiss private consumers. The service lifetime and disposal pathways are fed into a dynamic MFA model to calculate the stocks and flows of business devices. With the example of indium, neodymium and gold, the material resources contained in these stocks and flows are illustrated.

1 Introduction

Electronic devices contain many important resources, not only bulk material such as iron, aluminum, copper and plastics, but also critical raw materials such as indium and neodymium or precious metals such as gold, silver and platinum [1]. For an efficient management of these resources, it is important to know the quantities of electronic devices within the considered system boundaries, where they are located, how long they are used for and when and how they are disposed of. It is further relevant to know in what qualities the different raw materials within the devices exist [2]–[6]. Stocks and flows of electronic devices are often modelled with a dynamic material flow analysis (MFA) approach. Product lifetime and disposal pathways are essential aspects of dynamic MFAs. Existing literature mainly reports data on the use and disposal of electronic devices by private consumers, often based on household surveys or on-site evaluations at recycling facilities, e.g. [7]–[14]. The specific handling of business devices has rarely been assessed, although in a business environment, other mechanisms may determine their lifetime and disposal pathways.

In this article, we present the results of a study conducted in Switzerland in 2015, comprising interviews with 28 companies representing the Swiss corporate landscape regarding size, sector and the extent to which they use information technology (IT). The interviews addressed the current acquisition, usage and disposal policies of the companies with regard to business IT devices. We further inquired the influence of IT trends such as cloud computing or solid state drives (SSDs) on these policies and company practices and their potential future implications. Results are compared, where possible, to data collected from Swiss private consumers. The observed service lifetimes and disposal pathways are fed into a dynamic MFA model to simulate the stocks and flows of business devices. The flows of material resources are illustrated using the example of the following raw materials: indium, neodymium and gold.

Indium and neodymium were chosen as relevant critical raw materials on the basis of a multi stage selection and evaluation process [15]. An important field of application of indium in electronics is indium tin oxide in devices with liquid crystal displays (LCDs) [16]. Neodymium has been primarily used in permanent magnets since the 1990s. About 30% of all neodymium magnets are applied in hard disk drives, optical drives and loudspeakers in computers, as well as loudspeakers and vibration alarms in mobile phones [15], [17]. Both elements are also found on printed wiring boards (PWBs) [18]. In contrast to indium and neodymium, which are not yet recycled from electronics beyond laboratory scale, the recycling of gold is well established and therefore used as a reference case. Gold is applied in PWBs and connectors [19].

Device types included are desktop and laptop computers, mobile phones, monitors, flat panel display

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televisions (FPD TVs), external hard disk drives (HDDs) and servers, as they all contain significant amounts of indium, neodymium and gold.

2 Method

2.1 Data collection

In order to collect the data regarding the use and disposal pathways of IT devices in the business environment, a combined quantitative and qualitative research design was chosen according to a recommendation of Mayring [20]. Personal interviews were conducted with the executives responsible for IT infrastructure in Swiss companies. In the interviews both; the quantitative (acquisitions, service lifetime, use, storage, disposal etc.) and the qualitative aspects (IT policy implementation, reasons for disposal, future trends in IT use in business environment, etc.) were included. The quantitative part was strongly structured and the collected data were filled into a prepared table, whereas in the qualitative part open questions were used to gather information about the various aspects of IT use in enterprises and its future trends.

As the gathered data were used for an MFA model of Switzerland, the validity of the data was crucial. Due to limited resources, it was not possible to collect data based on a representative sample size of Swiss enterprises. The goal was yet to acquire the best possible data with a high validity for the business environment. Therefore we developed a sampling strategy that enabled to structure the sample of interviewed companies according to the structure of the Swiss business environment. As such the validity of the gathered data is increased and the data can be used for an MFA model of Switzerland.

The sampling structure was determined based on the following three criteria: sector, company size and IT-intensity. The criterion 'IT-intensity' needed to be given special attention, as the intensity of the IT use varies strongly among different industries, sectors and company sizes. Whereas for the criteria 'company size' and 'sector' the data of existing statics were used [21], for the 'IT-intensity' a multicriteria indicator was developed, consisting the following three variables: share of companies implemented a given IT infrastructure (e.g. Desktop, Laptop, Server) [22], share of investments into IT [23] and the share of the employees having access to a given IT infrastructure [24]. The agricultural sector was excluded due to a low relevance to the use of IT devices. The industry and service sector were merged and distributed to branches of similar IT-intensity. Finally, based on the statistical data, the Swiss company population was divided into nine clusters regarding size and IT-intensity. Table 1 shows the clusters and the share of Swiss companies in each of them.

Company size → IT-intensity↓	**< 50**	**50-250**	**> 250**
Low	Cluster 1: 13%	Cluster 2: 3%	Cluster 3: 10%
Medium	Cluster 4: 20%	Cluster 5: 10%	Cluster 6: 13%
High	Cluster 7: 13%	Cluster 8: 7%	Cluster 9: 10%

Table 1: Clusters based on company size and IT-intensity

Based on the sampling structure, suitable companies representing the given cluster were approached with the request to participate in the study.

For the MFA model, inflow data for desktops, laptops and monitors are provided by annual IT market reports for Switzerland, which include both the business and the home segment [26]. Where necessary, the inflow data for business devices were extrapolated based on the available time series. For other device types, currently no business sales data are available, which is why they are not included in the MFA. The service lifetime was modelled as a two-parameter Weibull distribution function, which was fitted to the relative frequency histograms of the service lifetime data (see also section 2.2). The lifetime and disposal pathway data for private consumers were taken from Thiébaud et al. [25]. The indium, neodymium and gold content was taken from literature [1], [17], [19], [27], [28] and own measurements [15], [18], [29]. For devices with various data available, the average metal content was taken. For desktop and laptop computers, currently a technology change from HDD to solid state drives (SSD) takes place. The resulting decreasing neodymium content was modelled by combining a model for devices with HDDs and one for devices with SSDs.

2.2 MFA model

The MFA system includes the process 'use phase' with an in-use stock of business devices. The system has one inflow which corresponds to sales of new devices and the five outflows 'electronic waste (e-waste) collection', 'donation', 'resale', 'back to retail' and 'transition to private use'. Besides the transition to private use, the donation and resale flows both include reuse of the obsolete devices, either in Switzerland or abroad. Also devices that are returned to dealers are possibly reused. The stocks and flows shown in grey color are not included in the dynamic MFA (Figure 1).

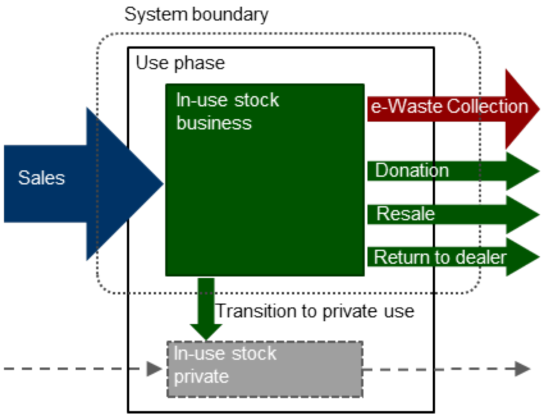

Figure 1: MFA system.

The model employs a retrospective top-down approach, deriving the stock *S[n]* at a time *n* from the net flow by using the balance of masses (equation (1)), with the constant sampling rate $T = 1$ year [30].

$$S[n] = (inflow[n] - outflow[n]) \cdot T + S[n-1] \quad (1)$$

The outflows of the in-use stock were calculated according to equation (2) [30]. As lifetime distribution function *f[m]*, the model applies Weibull distribution functions for the service lifetime of desktop and laptop computers as well as monitors.

$$outflow[n] = \sum_{m=-\infty}^{\infty} inflow[n-m] \cdot f[m] \quad (2)$$

The different outflows were determined by transfer coefficients. In order to calculate the indium, neodymium and gold flows, the stocks and flows of the dynamic MFA were multiplied with the respective metal content per device.

3 Results

3.1 Acquisition, use and disposal

The results presented in this section are based on the data gathered in 28 interviews conducted with the executives responsible for IT infrastructure in 28 Swiss companies from the second and third sector. The structure of the sample of Swiss companies participating in the study is shown in Table 2. The structure of the sample mirrors the structure of the Swiss company population reasonably well. As such the data can be used as good predictors for the whole population of Swiss enterprises.

It was found that for business use, always new devices are acquired, whereas the second-hand purchase rate of private consumers ranges from 10% for FPD TVs to 15% for monitors [25]. 25 of the interviewed companies acquire most of their electronic devices through central IT procurement departments, or, for smaller companies, directly through the CEO. Decentral acquisition occurs mainly for mobile phones by employees or FPD TVs according to specific needs of some departments.

Company size → **IT-intensity↓**	**< 50**	**50-250**	**> 250**
Low	Cluster 1: 14%	Cluster 2: 0%	Cluster 3: 11%
Medium	Cluster 4: 21%	Cluster 5: 7%	Cluster 6: 14%
High	Cluster 7: 18%	Cluster 8: 4%	Cluster 9: 11%

Table 2: Resulting sample structure

The median business service lifespan for mobile phones is 3 years. Laptops have a median service lifespan of 4 years, desktops, monitors, HDD and Servers of 5 years. The longest median service lifetime was observed for FPD TVs with 6 years. Compared to the service lifetimes of devices in a private environment, the medians are equal for mobile phones and desktops. For monitors and FPD TVs, the median for devices used in business is longer by one year, for laptops shorter by one year.

The comparison of the box plots of business and private service lifetime shows that the variance of the service lifetime of privately used devices is significantly larger for all device types (Figure 2).

Only around 20% of all companies have explicit service lifetime policies. These are often based on outsourced IT services, in which case the service lifetime is predefined in service contracts. Results show that the devices are used according to the policies or slightly longer (plus 0.5 to 1 year).

If we compare companies with low IT-intensity to companies with medium and high IT-intensity, the average service lifetime decreases for laptop and desktop computers, HDDs, servers and FPD TVs by at least 0.5 years, the more IT is used. The average service lifetime of mobile phones, however, is 0.5 years longer and for monitors, it is similar.

Companies with low IT-intensity indicated that electronic devices are primarily replaced when they are defect. For companies with medium and high IT-intensity, devices are more often replaced due to increasing performance requirements. Unlike private consumers, companies never store their obsolete devices for longer periods. The only devices stored are new desktop and laptop computers as well as monitors as supply for new employees.

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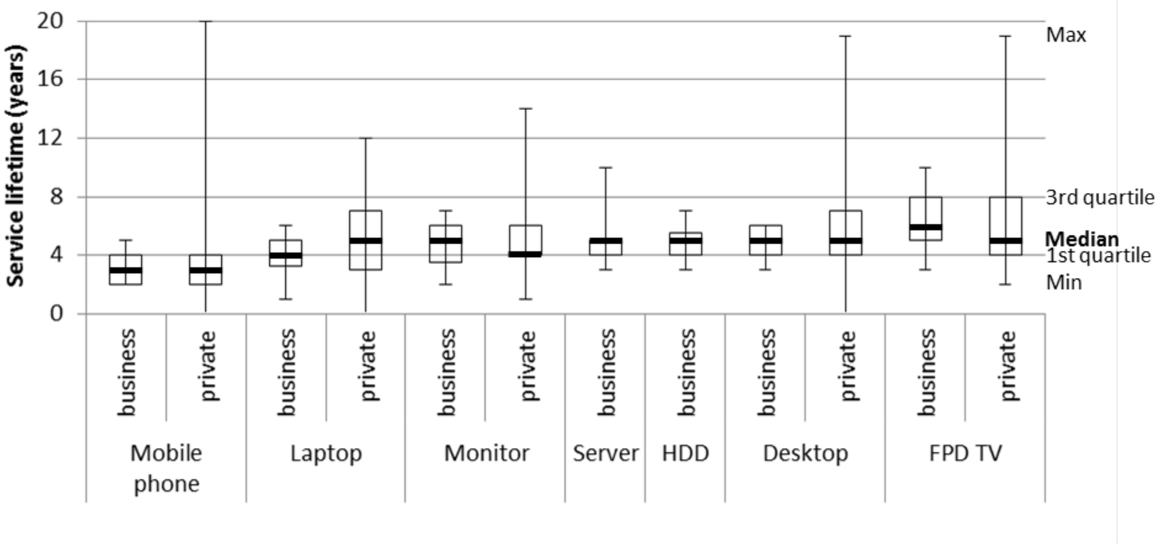

Figure 2: Comparison of box plots of business and private service lifetime.

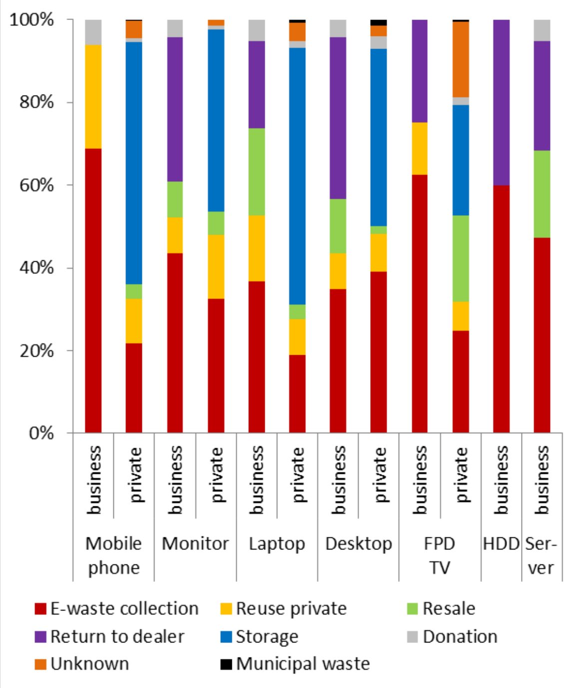

Figure 3: Comparison of disposal pathways of business and private consumers.

E-Waste collection is the mostly chosen disposal pathway for all business device types, followed by return to dealer and reuse. Exceptions are desktop computers, which are mostly returned to dealers. As indicated by the interviewed companies, the disposal pathways have not significantly changed in the last 10 years.

The main disposal pathway for private consumers is storage of obsolete electronic equipment, followed by collection and reuse. Devices from private consumers are more often given away for private reuse, whereas business devices are more often resold. The disposal pathways of business devices, compared to private consumers, are shown in figure 3.

3.2 Future trends

Around 60% of all interviewed companies already use cloud computing, while 15% plan to use it in the future. The cloud services they use are very diverse and range from general services provided by companies such as Dropbox and Google to very specific internal company services.

The share of companies that already use SSDs instead of conventional HDDs in more than half of their devices amounts to 40% for desktops and servers and 70% for laptops. In the future, the sole acquisition of devices containing SSDs is planned by 80% of all companies for laptops, 70% of all companies for desktops and 40% of all companies for servers.

3.3 Dynamic MFA

3.3.1 Inflow

The sales of desktop and laptop computers as well as monitors in the business sector have all been highly fluctuating in the past years. Desktop and monitor sales are slowly declining, while laptop sales are still increasing (Figure 4).

3.3.2 Stock

The business stocks of desktops, laptops and monitors in Switzerland, resulting from the dynamic MFA, account for about 2.0 million desktops, 1.9 million laptops and 2.2 million monitors in 2014 (Figure 5).

While the stocks of desktops and monitors are declining, the stock of laptops is constant.

The considered devices represent a total indium stock of 400 kg, a neodymium stock of 16'000 kg and a gold stock of 1'400 kg for Switzerland in 2014. The indium and gold stocks are decreasing due to decreasing stocks of desktops and monitors. The neodymium stock is decreasing due to the technology change from HDDs to SDDs (Figure 6).

3.3.3 Outflow

The outflows to the various disposal options are illustrated for 2014 in figure 5. According to the transfer coefficients derived from the collected data, the largest outflow reaches the e-waste collection system, followed by flows back to the dealer.

The stocks and flows of the different device types considered in the dynamic MFA are all of a similar order of magnitude. The flows to the e-waste collection account for around 40% of the metal outflow, with 30 kg of indium, 1'400 kg of neodymium and 110 kg gold. Thus 60% of the metal outflow is either transferred to reuse or returned to the dealer.

4 Discussion

The data regarding the IT use, lifetime and disposal in the business environment are based on the relatively small sample of 28 companies. However, due to the special sampling method aiming to match the structure of the sample with the structure of the Swiss enterprise population regarding size and IT-intensity, the validity of the data is increased. Therefore the authors believe that it should be possible to use the collected data as a good predictor for the use of IT devices in the whole population of Swiss enterprises.

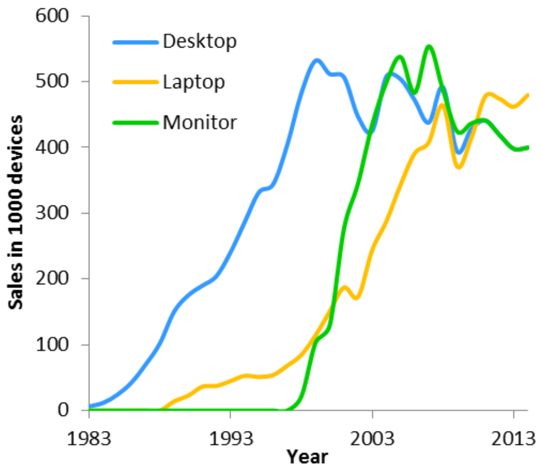

Figure 4: Sales from 1983 to 2014 in 1000 devices.

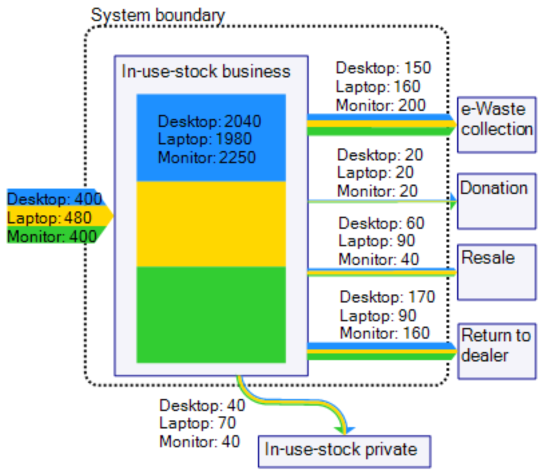

Figure 5: Inflows, stocks and outflows of business IT devices in 2014, in 1000 pieces.

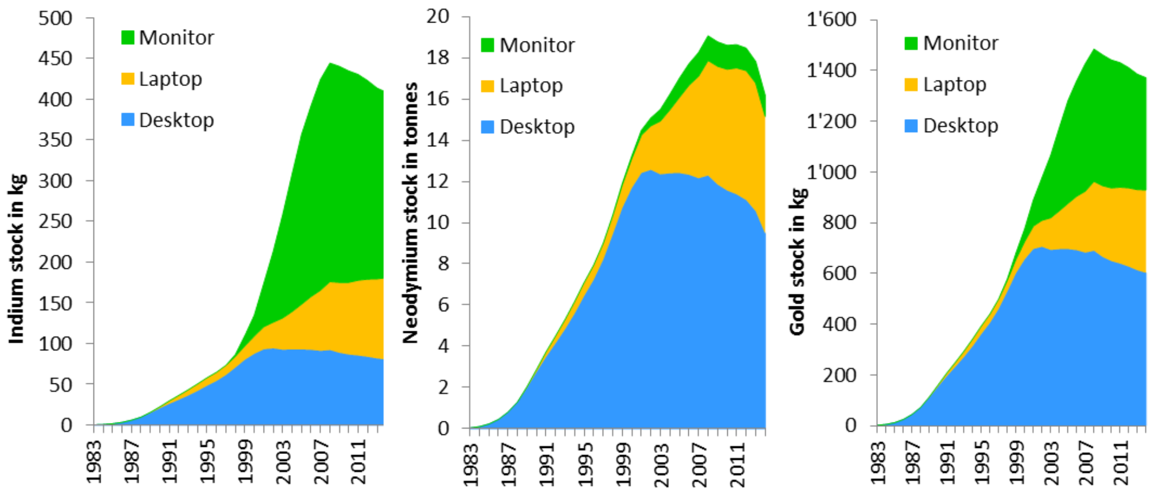

Figure 6: Indium, neodymium and gold stocks from business devices.

Business devices are mostly acquired through central IT procurement departments, often based on predefined selections. This limits the diversity of devices in use, compared to private consumers. The median service lifetime of business devices is similar to the service lifetime of privately used devices, but with a much smaller variance. In the private environment, expectations regarding the performance of devices vary greatly, for example, a 10 year old and slow computer can still be used for text processing, while for online gaming, a new and fast model is required. In the business environment, computers older than 6 to 7 years do not seem to meet the performance requirements. However, a systematic replacement of business devices after a predefined service lifetime does not take place in most companies. Service lifetime thus also varies within companies, but the variance is indicated by the interviewees as small (± 1 year) for all device types with the exception of HDDs and servers.

Explicit service lifetime policies are mostly based on outsourced IT services. The average policy service lifetime is shorter than the actual average service lifetime for all devices except for HDDs. Outsourcing of IT services, which is a trend mainly among medium-sized and large companies, therefore seems to have a negative influence on the product longevity.

Unlike private consumers, companies never store their obsolete devices for longer periods. Interviewees stated that there is no space for storage, except in a few cases for new devices.

Most devices are disposed of in the official Swiss e-waste collection system, where they are manually and mechanically dismantled and sorted into different material fractions such as metals, plastics, printed circuit boards etc. However, a large proportion of devices are returned to the dealer. The subsequent pathways are unknown and may include the official e-waste collection system, but also resales both in and outside Switzerland.

The three reuse pathways, donation, resale and transfer to private use, account for 10 to 40% of the outflow, depending on the device type. Both donation and resale involve reuse within Switzerland or abroad, however, the share of exported devices is unknown. Donation only occurs in two of the 28 interviewed companies, which indicates that the percentage of devices donated by Swiss companies might be overestimated. If devices are sold to another company, they are most probably exported, as most Swiss companies acquire new devices only. Otherwise we assume that they are sold to private consumers. The median service lifetime of second-hand devices among private consumers account for, e.g., 2 years for laptops, 3 years for mobile phones and monitors and 5 years for desktops [25]. Reuse of business devices in the private environment therefore significantly contributes to product longevity.

The dynamic MFA yields a very simple system, as business devices are not stored after their active use. The resulting quantities of indium, neodymium and gold only represent a share of the total indium, neodymium and gold in the business in-use stock, as there are other types of devices containing these metals. Neodymium is also found in HDDs and servers, and indium in FPD TVs. Gold occurs in all considered device types. If sales or stock data of all relevant device types were available, a more complete MFA of the considered metals could be accomplished. Indium, neodymium and gold from laptop and desktop computers and monitors in the business in-use stock have a value of 140'000 Euro for indium, 860'000 Euro for neodymium and 51 million Euro for gold. This illustrates that besides physical and chemical properties and technological aspects, expected revenue is an important factor, and explains why the recycling of indium and neodymium is not yet established.

Only around 40% of all devices – and thus also the resources contained therein – directly reach the collection system. 60% of all resources are incorporated in devices that are reused either within or outside Switzerland, or with an unknown fate. For a better tracking of resources, knowledge on disposal pathways should be enhanced.

Technological changes such as the transition from HDDs to SSDs in laptop and desktop computers and servers are relevant for Swiss companies. This specific transition will eventually lead to diminishing inflows of neodymium. In the outflow, however, neodymium will still play a role for recycling facilities in the next one or two decades, as devices reach the collection system with a delay. The delay is more predictable for IT devices in the business sector, as the service lifetime shows less variation, but if devices are transferred to private use, private service lifetime and even storage may prolong the time until a device is collected for recycling.

5 Conclusion and Outlook

Product lifetime and disposal pathways of business devices have rarely been assessed, although, compared to private consumers, they are determined by different mechanisms. In this article, we presented the results of a study on the service lifetime and disposal pathways of seven different device types, which are used in the business environment and contain significant amounts of indium, neodymium or gold.

Although in many companies, the acquisition and disposal of devices is administered centrally, the service lifetime of a specific device is often not based on lifetime policy but either on performance or operation. The median service lifetime is similar to the one of privately used devices, although the variation of private service lifetime is significantly larger. Whether this can be explained by a longer maximum service lifetime of privately used devices (due to less intensive use or lower performance expectations), could not be answered within this study and could be explored in future research.

As obsolete business devices are not stored, there is no delay of the reintegration of secondary resources into the material cycles. However, as devices are often returned to the dealer or reused, it is difficult to keep track of the resources they contain. Future research could analyze business disposal pathways in more detail, including the flows and destinations of devices that are resold, donated or returned to the dealer.

The simple MFA model allows quantifying stocks and flows of business devices and the resources they contain. Especially in the business sector, it is more difficult to get sales or stock data for a larger range of device types, as such data are not disclosed by the dealers. It is therefore currently not possible to include all relevant business device types for a comprehensive MFA of indium, neodymium or gold. Besides finding better sales or stock data, future research could combine the current MFA model with a model of private IT use, since many devices are transferred to the private environment, either directly or through resale.

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